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Transall C-160 Life Extension and Avionics Upgrade Programs

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Summary:

Objektives: Since 1967 the Transall C-160 is the transport aircraft of the German Air Force. After carrying out of life extension measures, avionics upgrade and other improvements of the technical equipment, the Transall C-160 can be operated under economical conditions far beyond 2010.

Description: Life extension measures for C-160 started in 1984 (LEDA I and LEDA II). These measures were only carried out for the wings. After taking apart the aircraft in this high scope, more than 30% of complaints were discovered in comparison to the normal preventive maintenance activities. As a result an investigation of aircraft areas and zones not yet subject to inspection measures (PUNIB) was carried out. PUNIB was the basis for LEDA III. In LEDA III the whole structure of the aircraft was inspected. In this manner the life time of the aircraft was extended step by step. Primarily the specification of the original air frame lifetime was restricted to 1995 or 8000 flights (LEDA I, LEDA II). After LEDA III the lifetime for C-160 was extended to 2010 or 12000 flights. Because of the spare part situation avionics upgrades in 1987 and the replacement of the flight management system (FMS) and the flight control/flight director system (FCS) in 1993 in combination with the replacement of the wiring was carried out. These measures will be finished in 1999. Over and above, the replacement of the intercom system, the improvement of the selfdefense suite and the integration of a traffic alert and collision avoidance system (TCAS II) as well as other technical measures will be taken. These increase the reliability and improve the precision of the mission management. Moreover the spare part situation was improved since the mid 80's by the aircraft update programmes.

Results: The life extension technical measures and the avionics upgrade programs increased the reliability, improved the precision of the mission management and in the longer term the provision of spare parts. Because of the life extension measures and the avionics upgrade programs the C-160 fleet can be operated beyond 2010. The last aircraft needs to be grounded not before 2018. Over 50 years in service, which proves the effectiveness of the

described measures and indicates that upgrade programmes can be an economical alternative to the procurement of new systems.

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1. Brief History of Transall C-160

On April 16, 1959 the production of a total of 218 aircraft was started by signing the Transall Cooperation Contract. Major participants in design and production were the companies:

- Nord Aviation
- Hamburger Flugzeugbau GmbH
- „Weser“ Flugzeugbau GmbH
- Prof. W. Blume Leicht- und Flugzeugtechnik GmbH

Between February 1963 and February 1964 the first flights of 3 prototype aircraft took place. 169 aircraft of a first series were produced and delivered in a timeframe from 1967 to 1973:

- 50 A/C for France
- 110 A/C for Germany
(later 90 A/C for GAF, 20 A/C for TAAF)
- 9 A/C for South Africa

During the initial production series the three partner companies produced individual major components such

as fuselage front, center and tail sections in addition to main wings and empennage. Each company shipped their produced components to the other partners where each then did final assembly at lines in Hamburg, Bremen and Bourges.

Since 1979, within 7 years, 35 aircraft were produced in a second series:

- 29 A/C for France
(25 A/C standard version, 4 A/C special mission)
- 6 A/C for Indonesia

Contrary to the initial series, the second series consisted of the same production sharing in Hamburg, Bremen and Toulouse, however with only one final assembly line in Toulouse.

The A/C of the second series differed from the first series A/C as follows:

- Capability for aerial refuelling (25 A/C)
- Tanker mission (10 of 25 A/C)
- Modern communication system
- Modern navigation system

Here are the main technical data of the Transall C-160:

Wing span	40.0 Meters
Overall length	32.4 Meters
Total height	11.8 Meters
Max. T.O. weight	49.2 Tons (1 st lot)
	51 Tons (2 nd lot)
Max. payload	16 Tons
Max. fuel capacity:	16,000 Liters (1 st lot GER)
	19,000 Liters (1 st lot F)
	28,000 Liters (2 nd lot)
Cruise speed	485 Km/h
T.O. distance	650 Meters (43.8 Tons)
Landing distance	580 Meters (40.1 Tons)
Max. range	4,560 km (1 st lot GER)
	5,415 km (1 st lot F)
	7,980 km (2 nd lot)
Usable cargo space	139.9 m ³

The German Air Force Transall C-160 was designed for the following missions:

1. Cargo (includes dropping of cargo from low to extremely low heights)
2. Transportation of personnel
3. Dropping of paratroopers
4. Transportation of wounded personnel
5. Fire fighting missions

Today, the French C-160 aircraft are maintained by AIA/CIT (Atelier Industriel Aéronautique/Cellule Industrielle Transall) in Clermont-Ferrand. The engineering is done by Aerospatiale in Toulouse.

The German C-160 fleet is supported in depot level maintenance and engineering by DaimlerChrysler Aerospace in Manching.

The logistical support is done by the weapon system companies AIA/CIT, Aerospatiale and Dasa M which includes besides depot level inspections, modifications, upgrades and supply of spareparts and documentation.

2. Life Extension Measures

According to the „Technical Specification Series Aircraft“, the lifetime of the Transall C-160 was designed for 5,000 flights, thereof 625 low level flights. At that time the calculation was based on 2 flight hours per flight. Since the first aircraft were delivered to the German Air Force in 1967, the aircraft could have been used until 1990 (theoretically). In reality, however, one flight took only an average of 1.22 flight hours. This resulted in a reduction of the in-service time by almost 40%. This forced an early conception of adequate measures, that would allow to operate the A/C in excess of 5,000 flights. This resulted in the so-called LEDA measures, where LEDA is a German acronym for „Lebensdauererlängernde Maßnahmen“ (Life Extension Measures).

The following measures were taken with respect to the structure of the A/C:

2.1	Preparatory work for LEDA	
2.2	LEDA I / II	1984 - 1990
2.3	PUNIB	1987 - 1988
2.4	LEDA III	1988 - 1999

2.1 Preparatory Work for LEDA

2.1.1 Tests on the Dynamic Fatigue Test Airframe

Extended tests were run, among others, the induction of artificial cracks with defined length and a certain crack configuration. The progress of the crack was monitored under operational conditions and with different loads:

- purely exterior load,
- purely interior pressure load changes and
- exterior load overlapping with interior pressure load and changes.

The tests were performed on the dynamic fatigue test airframe especially in the areas of the center fuselage, wing and after fuselage section. The result of the tests corresponded very favorably with the calculated crack progress data.

2.1.2 Inspections of Older Aircraft

Aircraft with an average of 2,800 flight hours were inspected to determine the degree of damage of these aircraft. Critical areas were examined with respect to vibration cracks and corrosion, respectively. For example, 500 rivets on the underside of the wing were removed and the holes tested with eddy-current.

2.1.3 Minor Tests for Determining Adequate Cold-Working Procedures

Sample mandrels were tested to determine the optimum degree of the cold working required. Two different expansion procedures were considered:

- the Aerospatiale (AS) procedure and
- the Boeing Split-Sleeve Cold-Expansion procedure.

Using the AS procedure, the expansion tool acts directly on the wall of the fastener hole and there is the risk of contamination, grinding and scratching. Using the split-sleeve cold-expansion procedure the mandrel acts on a sleeve inserted into the drillhole and therefore indirectly on the wall of the drillhole. The resulting burrs on the slit of the sleeve can be removed by a deburring tool.

The objective to extend the lifetime distinctly can be achieved with both procedures.

The Aerospatiale procedure was used on the French Transall C-160's. Germany decided to use the split-sleeve cold-expansion method since the improvement factor was considered to be higher with this procedure.

2.1.4 Component Tests

The objective of the tests was to determine the influence of the expansion of rivetholes on the lifetime of individual components. The result of those component tests was, that in certain areas a high degree of stiffness and high level of tension existed, for example in the area of structural doublers. By cold-working of this area alone, life would be extended up to a factor >2. This also means, that 8,000 flights could have been reached without additional measures like LEDA, if the holes would have been cold-worked during aircraft production.

2.2 LEDA I/II

LEDA I/II includes life extension measures in the wing area. This encompasses the replacement of 5,148 close tolerance fasteners, 630 standard rivets and 3,168 rivet holes cold-worked per aircraft. Additionally doublers were installed on the wing center sections and the outer wings. LEDA I/II measures were taken between 1984 and 1990 after 4,200 flights.

2.3 PUNIB

PUNIB is a German acronym for „Programm zur Untersuchung nicht inspizierter Bereiche“ (investigation of aircraft areas and zones not yet subject to inspection measures). Using non-destructive inspection procedures (eddy-current, roto-test, magnaflux, dye-penetration procedures), visual and tolerance inspections were made in areas that had not been subject to planned inspections according to the inspection manual up to that time. The program was decided on in 1986, the contents defined, and performed on 1 Turkish and 3 German aircraft in 1987/1988. The result of these tests was, that extensive measures are required, especially in areas outside environmentally controlled fuselage.

2.4 LEDA III

The PUNIB tests formed the basis for the LEDA III program, divided into Immediate Action Measures and Follow-On Measures.

The Immediate Action Program was executed from 1988 to 1992 in order to limit the effects of the damage. These were measures like empty space preservation, corrosion treatment and changes of material, etc.

For short, empty space preservation is described as an example:

In this case, the most suitable anticorrosion chemical had to be found, for the materials used on the Transall C-160 for:

- Accessible areas (horizontal and vertical fin)
- Non-accessible areas (ailerons, flaps)
- Installed parts (struts, control rods).

Prior damaged samples were exposed, for example to salt fog or spray water tests. The best corrosion protection was achieved by the chemical DINITROL AV 5 and DINITROL AV 100, which generates a firm protective film.

The second part of LEDA III, the Follow-On Measures, was executed from 1991 to 1999.

Results:

By means of life extension measures (LEDA), the A/C life was successfully and successively extended:

- LEDA I – measures (cold working in wing area) to 8,000 flights, utilisation up to 1995
- LEDA II – measures (reinforcement of the wing area)
- LEDA III – prevention and corrective measures on the entire airframe to more than 12,000 flights and an utilisation of at least up to 2010.

The German Transall C-160 fleet has nowadays an average airframe life time of 29 years and an average of 8,000 flight hours airframe stress (in comparison, the French fleet of the first production series has 15,500 flight hours at the average).

3. Avionics Upgrade Measures:

Since the introduction of the Transall C-160 in 1967, approximately 2000 upgrades and modifications were incorporated:

- approximately 60 % with respect to the structure
- approximately 40 % with respect to the equipment.

These measures encompass the following aspects:

- 3.1 Avionic modifications
- 3.2 ANA/FRA and new wiring
- 3.3 ELOKA, INTERCOM, TCAS II.

Objective:

It was the objective of the modifications to replace avionic equipment that could no longer be supported and simultaneously to upgrade the avionics to the present state-of-the-art. Also, in order to obtain a centralised control and display system, which allows the central operation of the communication and navigation system via CDU (Control and Display Unit).

3.1 Avionic Modifications

Within the scope of life time extension measures, parts of the avionics system were renewed in parallel. In a first step, HF, WX-radar and radio-altimeter were replaced by newer equipment and additionally a SELCAL and data transmission system were installed.

3.2 ANA/FRA and New Wiring

Two objectives were behind the installation of the ECM-resistant Autonomous Navigation (ANA) and Flight Control/Flight Director (FRA) System.

- 1. Objective: Improving the reliability and accuracy of the navigation system / Reduction of maintenance cost**

This was achieved by the:

- Replacement of the obsolete Syp 820, C11, Doppler, PHI and LORAN equipment by the Autonomous Navigation System (ANA) consisting of
 - LINS: Laser Inertial Navigationssystem
 - GPS: Global Positioning System

ADC: Air Data Computer
 EHSI: Electronic Horizontal Situation Indicator and the

- Installation of a new Flight Control/Flight Director System (FRA):
 - SPZ 450: new Autopilot
 - AHRS: Attitude/Heading Reference System

- 2. Objective: Change of the operating and crew concept**

- New operating concept:

As mentioned before, after the installation of the ANA/FRA system, the entire communication and navigation system can be centrally operated and controlled by the pilot and the co-pilot via Central Display Units. In order to do that, it was necessary to connect the various equipment of the Autonomous Navigation system via a data bus according to MIL STD 1553 B.
- New crew concept:

There is no longer one unflexible crew concept, but there are two alternatives:

 - a 4-man crew for tactical missions and short distance flights and
 - a 3-man crew for medium and long distance flights (without navigator)

With these alternatives, personnel and mission planning becomes more flexible and, on the other hand, the number of personnel can be reduced.

The time schedule for the ANA/FRA-program is described by the following mile stones:

II/87	Completion of concept phase
III/89	Completion of preparatory work development phase
IV/89 – IV/93	Development phase, kit-proofing, and integrated testing
III/93 – XII/99	Incorporation in series A/C

In parallel to the ANA/FRA installation in the C-160, the entire A/C wiring was replaced 1:1. This amounts to approximately 40,000 meters of cables per A/C.

3.3 ELOKA, INTERCOM, TCAS II

3.3.1 ELOKA

In order to improve the self-protection capability of the Transall C-160, an anti-aircraft-fire-protection system using kevlar and armoured plates was incorporated into all 86 A/C of the German C-160 fleet from 1992 to 1999 and a self-defense system was installed into 24 A/C.

The self defense system consists of the following components:

- Radar Warning System
- Chaff/Flare Dispenser
- Missile Approach Warning System
- Electronic Warfare Management System

3.3.2 INTERCOM

In 1998/1999 the kit-proofing of a new INTERCOM system was completed. It will be incorporated into the fleet starting in 2000. This retrofit measure became necessary since the logistical support for the 40 year old intercom system was no longer secured and because of additional operational requirements of the German Air Force.

3.3.3 TCAS II

TCAS II will be required by law for commercial A/C with more than 30 seats and/or more than 15 tons of weight within European air space after January 1, 2000. Furthermore a USAF C-141B Starlifter collided with a Tupolev TU-154 of the GAF off the African west coast on September 13, 1997. A collision that might have been avoided by TCAS. For this reason, the German Transall C-160 will be equipped with a collision warning system. It will be installed within the next 3 years.

Besides these projects, measures like the renewal of the VOR/ILS and replacement of the IFF transponder STR-700 by STR-2000 are presently prepared.

4. Life Extension Measures as an Economic Alternative ?

Life extension measures and avionics upgrade as described became necessary in order to keep the fleet operational in the short and long terms.

These measures improved

- the availability of the A/C and
- the accuracy of the mission management.

In the long run,

- an improvement of spare provisioning and

- the extension of the life time of the C-160 fleet beyond 2010 was achieved.

According to the present planning, the last A/C is not to be phased out before 2018. An average service life of more than 50 years proves the quality of the described measures.

The question, however, may be discussed, whether extending the life time by 150% or 30 years is in general an economical alternative, compared to the introduction of a new system. This must be considered and calculated individually for each weapon system. The costs for all the upgrade programs were less than 20% of the A/C purchase investment cost. In comparison the A/C in-service time was extended more than 150%. This means that, in case of the Transall C-160, the upgrade programs were and are a cost-effective alternative.

List of Abbreviation

A/C	Aircraft
ADC	Air Data Computer
AHRS	Attitude/Heading Reference System
AIA	Atelier Industriel Aéronautique
ANA/FRA	Autonome Navigationsanlage und Flugregelanlage
	Autonomous Navigation and Flight Control/Flight Director System
CDU	Control and Display Unit
CIT	Cellule Industrielle Transall
EHSI	Electronic Horizontal Situation Indicator
ELOKA	Elektronische Kampfführung Electronic Warfare
F	France
GAF	German Air Force
GPS	Global Positioning System
ILS	Instrument Landing System
INTERCOM	Intercommunication System
LEDA	Lebensdauer verlängernde Maßnahmen; Life extension measures
LINS	Laser Inertial Navigation System
NDI	Non-destructive inspection procedure
TCAS	Traffic Alert and Collision Avoidance System
TUAF	Turkish Air Force
USAF	United States Air Force
PUNIB	Programm zur Untersuchung bisher nicht inspizierter Bereiche; Investigation of aircraft areas and zones not yet subject to inspection measures
VOR	Very High Frequency Omnidirectional Radio Range